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Soil Water Retention Curve of an unsaturated sand under square footing considering matric suction

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Abstract - *Majority of the geotechnical engineering projects are taking place in unsaturated soil zone. Engineering aspects of these kind of soils are not in concern with many designs. Study of unsaturated soil behavior involves study of matric suction and volumetric water content. One of the application in which matric suction is involved is the design of shallow foundation. Matric suction controls the unsaturated soil behavior. It is the pressure exerted by the soil on its surrounding soil to equalize the moisture content of the entire soil mass. In this study the ultimate bearing capacity of a well graded sand is determined using plate load test controlled by matric suction under natural, fully saturated and unsaturated state. Initial tests like Atterberg limits, specific gravity, grain size distribution, hydrometer and compaction tests were done for soil sample. The ultimate bearing capacity for unsaturated soil under square footing is considered. Using plate load tests, the bearing capacity value controlled by matric suction the footings are measured from the load – settlement curves. Theoretical bearing capacity is obtained from modified Terzaghi's equation. The results are compared for the validity of bearing capacity values. The relation between the bearing capacity and matric suction is also computed. Currently, design of foundations are based on conventional soil mechanics. This study helps to understand the role of partial saturation in design considerations and to analyze the practical applicability of a matric suction in shallow foundation design.*

***Key Words*: Shallow foundation, unsaturated soil, matric suction, plate load test, filter paper method, SWRC, Ultimate bearing capacity.**

1.INTRODUCTION

The classical soil mechanics considers soil as a two phase system which consists of soil and water. But it is not valid in real life problems like embankments, slopes, dams, road pavements, foundations etc. In these situations soil is in a three phase system or unsaturated state which consists soil, water and air. Usually shallow foundations are located above the ground water table where soil is in a state of unsaturated condition. But the bearing capacity of soil is determined considering the fully saturated state ignoring the effects of matric suction. As a result the estimation of the bearing capacity of shallow foundations will lead to uneconomical designs. In this study, Filter paper method is used to evaluate the matric suction of soil. Matric suction plays a vital role in developing the shear strength of soil. It is an important tool in interpreting the engineering behaviour of unsaturated soils. It has got many geotechnical applications. Study of variation in matric suction solves unsaturated soil slope stability and soil bearing capacity. The ignorance of the increase in shear strength due to the effect of matric suction leads to the under-estimation of bearing capacity. So there is a need to study the effect of matric suction values to the bearing capacity of unsaturated soils. Plate load test is commonly used to determine the bearing capacity of soils usually above ground water table where soil is in an unsaturated state.

The main objectives of this study are:

- To determine the bearing capacity of square footing controlled by suction by plate load test in the laterite soil.
- To determine the matric suction of the soil sample taken after plate load test.
- Plotting the SWRC of soil.

Studies have done to investigate the effect of matric suction on the unsaturated bearing capacity of soils. There is limited research work is recorded in the literature reviews. Hamzah and Al-Hashemi ,(2018);They have done a work on

the estimation of SWCC for unsaturated soils and its application to design of shallow foundations by conducting Atterberg limits,compaction,SEM,XRD,Filter paper method etc. They found that void ratio decreases with suction by 19.25% in both dry and wet of optimum and suction can be used as a soil improvement technique. Yi Tang et.al, (2018); They have studied on the influences of Suction on Plate Load Tests on Unsaturated Silty Sands by conducting Plate Load Tests and observed that assuming matric suction, the bearing capacities recovered from the equations are in reasonable agreement with the values measured in the PLTs, with differences less than 30% . Matura asmi et.al (2016); They determined the soil water characteristic curve of mining sand using pressure plate testing methods and found that initial water content and grain size has influence on SWCC.For normal mining sand reduction in water content due to suction is 86.6%,for sand without 2mm 82.6% and 98.3%. Xiang- hui Hu et.al (2011); They have studied the matric suction characteristics and its influences on the stability of landslide modified triaxial test using triaxial compression test. The strength of soil was appeared to increase by 46.3% with the increase of suction. With the reduction of the suction the stability coefficient of landslide will decrease. Pressure plate tests and filter paper method are effective for suction measurement. The bearing capacity of unsaturated sands increases with matric suction .Matric suction can be used as a soil improvement technique. There is limited consideration for matric suction in the design criteria of shallow foundations.

2. METHODOLOGY

The methodology consists collection of the soil sample from Neyyardam region of Kerala. The index properties of collected samples are determined in the initial stage. In the second stage, bearing capacity of the soil is done under square footing. Matric suction is obtained for the samples extracted from tank. Using matric suction and degree of saturation values, the Soil Water Characteristic Curve is drawn.

2.1 Plate load test

To determine the bearing capacity of soils, plate load test is conducted according to IS 1888:1982. In order to incorporate the effect of matric suction, plate load test apparatus is provided with a mild steel pipe at a corner near the bottom of the tank platform for the purpose of drainage of water. Soil is to be filled in the tank to obtain a relative density of 50%.A strainer is to be provided at the outlet pipe to prevent the loss of soil. Once the soil is filled, test is done under natural condition. Then water is supplied to the tank through a small pipe at the top of the tank. Water is allowed to fill the tank upto the soil surface. Then the soil is allowed to soak for 24 hours. After the complete soaking, plate load test is done in this fully saturated condition. Then the water is allowed to drain out of the tank through the outlet pipe. The tank is kept in this condition for another 2 days for complete drainage. After that soil will achieve an unsaturated condition. Then the plate load test is done to obtain the ultimate bearing capacity of soil.

2.2 Filter paper test – matric suction measurement

The samples for the matric suction study is extracted from the plate load tank just after the test under unsaturated condition from a depth, d = 4cm, 12cm, 20cm and 28cm. The sampling depth is limited upto the midheight of soil filled in the tank. A sampler extruder made of PVC pipe is used. The extruded soil samples are subjected to filter paper method.

The Whatman filter paper no.2 grade is sandwiched between two larger size protective filter papers. Sandwiched filter papers are inserted into the soil sample. This is for the matric suction study in which filter paper is in direct contact with the soil. The soil should be sufficiently moist in order to wet the filter paper. Some amount of soil is taken for water content determination also. The soil samples with embedded filter papers are put into container. The container is sealed up very tightly with plastic tape. The entire arrangement is kept in equilibrium for about 10 days. After the soil samples reached equilibrium, the enclosed containers are opened and the filter papers are taken out from each sample using a forceps. Four cans with their lids were taken for samples at each depths and their cold weights (T_C) were recorded. Then the filter paper is placed into the can and closed by the lid and weighted (M_1) without moisture content loss. The same procedure is done for remaining samples.

After that, the cans were kept partially closed in the oven for 2 hours, and then completely closed for 15 minutes. Later the cans from the oven are allowed to cool down and their weights were recorded (M_2). The filter papers were disposed of. Hot weights of the cans and lids were recorded as T_H. The moisture content of each filter paper (W_F) was then calculated from Eq. 1.

$$W_F\,(\%) = \frac{(M_1 - M_2 + T_H - T_C)}{(M_2 - T_H)} \times 100 \quad (1)$$

(Source: E.-C. Leong et. Al, 2016)

The matric suction values ($u_a - u_w$) of soil samples at different depths is obtained from the following equations.

For $W_F \geq 47\%$:

$$\log[(u_a - u_w)] = 2.909 - [0.0229 \times W_F] \quad (2)$$

For $W_F < 47\%$:

$$\log[(u_a - u_w)] = 4.945 - [0.0673 \times W_F] \quad (3)$$

Plotting matric suction against the saturation degree of soil, soil water characteristic curve (SWRC) is drawn. The air entry value (AEV) of the soil is taken as the point of intersection of tangent.

3. MATERIALS USED

3.1 Sandy soil

For the study, sandy soil is collected from Neyyardam region and the index properties of soil were tested which is given above in table 1. Obtained that the sand is well graded.

Table 1. Index properties of sandy soil.

Soil properties	Values
Specific gravity	2.53
% of silt	0.4
% of sand	93
% of gravel	6.6
Angle of friction(°)	16.5
Minimum dry density(g/cc)	1.29
Maximum dry density(g/cc)	1.46
C_u	7
C_c	1.75
Soil specification	SW
Permeability (mm/s)	8.09×10^{-3}

3.2 Whatman filter paper no. 2 grade

The filter paper used for the matric suction study is the Whatman filter paper no.2 grade obtained from the supplier.

3.3 Square footing

The square footing used for the bearing capacity study is made of mild steel with dimension of 120 mm x 120 mm.

4. RESULTS

The relevant results obtained for the study under plate load tests and filter paper tests are as given below:

4.1 Plate load test in sandy soil with square footing

Plate load test was done under fully and unsaturated condition and the load settlement details were obtained. Comparing the bearing capacity values as in the chart.1, it is observed that ultimate bearing capacity under natural condition is 402.77kN/m², fully saturated condition is 343.75kN/m² and that for unsaturated condition was found to be 451.4kN/m² which is higher due to the increased suction which gives strength to soil.

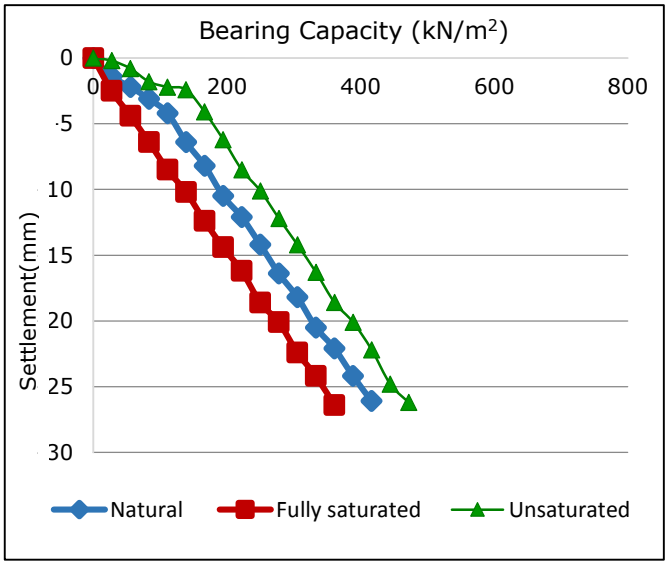

Chart 1. Comparison of Ultimate bearing capacity of soil at natural, fully saturated and unsaturated condition.

4.2 Matric suction determination

A PVC pipe extruder of height 25 cm and diameter 10 cm is used for extruding sample from the test tank from a depth of 4cm, 12cm, 20 cm and 28 cm. The samples are used for conducting filter paper test. Water content of the soil is also determined using oven dry method. The extruded samples are prepared for filter paper method as shown in fig 1.without any moisture content loss.

Fig -1: Arrangement of soil sample for the filter paper test

The soil samples with embedded filter papers are put into container. The container is sealed up very tightly with plastic tape. The entire arrangement is kept in equilibrium for about 10 days. The inner filter paper assembly at each depth was kept in oven. The variation of filter paper moisture content, matric suction and degree of saturation with depth upto midheight of tank are given in the table 2.

Table – 2: Variation of filter paper moisture content, matric suction and degree of saturation with depth upto midheight of tank

Depth (cm)	Filter paper moisture content (%)	Matric suction (kN/m^2)	Degree of saturation
4	23.07	29.73	0.56
12	25.5	25.25	0.68
20	28.8	20.8	0.79
28	32.6	15.6	0.88

Thus the variation of matric suction of soil with saturation degree of soil which is termed soil water retention curve (SWRC) and it is shown in fig.3.

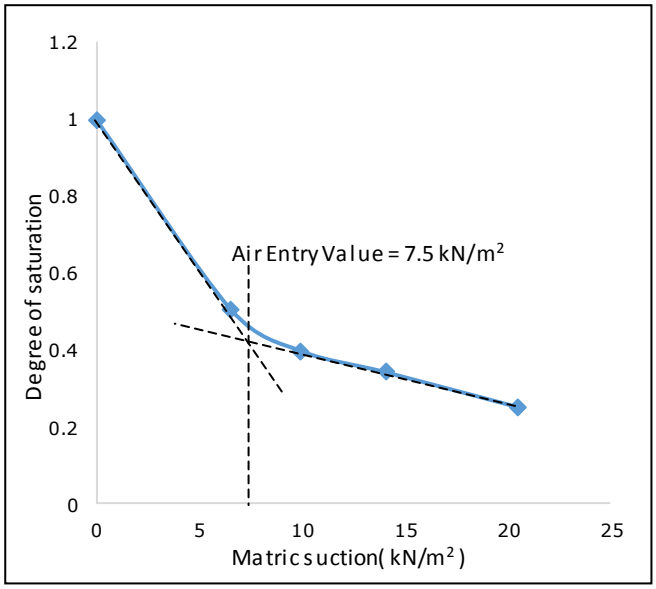

Fig.3 Soil Water Retention Curve of Sand with square footing.

5. CONCLUSION

There is a need to study the effect of matric suction on the bearing capacity of unsaturated soils. In this study the ultimate bearing capacity of a sandy soil is determined using plate load test controlled by matric suction. This study helps to prove the significance of matric suction to the bearing capacity of shallow foundation in unsaturated soils. Matric suction has got many applications in geotechnical areas. Here the area of concern is design of shallow foundation. Currently the concept of unsaturated soils are not in consider for engineers. This study may help the geotechnical engineers to analyse the practical applicability of matric suction in shallow foundation design.

The relevant points concluded from the study are given below:

- Bearing capacity of sandy soil under square footing in a natural condition was $402.77kN/m^2$, fully saturated condition was found to be $343.75kN/m^2$ while under unsaturated condition, bearing capacity increased to $451.4\ kN/m^2$. Because in a fully saturated state soil suction will be zero.
- The sandy soil gained 31% increase in bearing capacity under unsaturated state from fully saturated state due to the increased suction which gives it stability.

- From the SWCC plot of the lateritic soil with rectangular footing, AEV value was found to be 7.5 kN/m^2 .

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